UNCLASSIFIED

AD 413439

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA

UNCLASSIFIED

AUDITORY PAIN THRESHOLDS FOR INTERMITTENT, "BEAT" AND STEADY SIGNALS

ROBERT PLUTCHIK[1].

Hofstra University[2]

Summary.—Eight Ss were given audiograms and ear examinations to insure normality and then presented with a series of tones at either 1000 cps or 2500 cps. For each frequency the sounds were presented as constant tones, as interrupted pulses, or as "beats," the pulses and beats being given at repetition rates of either 3, 6, or 15 per sec. For each condition the intensity of the sound was increased by a series of steps. S was to indicate when the tone was "just noticeably unpleasant" (JNU) and when it was "just noticeably painful" (JNP). These thresholds were measured in terms of the db attenuation from a given maximum of 130 ± 2 db. It was found that individual pain thresholds varied from about 100 db to over 130 db, with unpleasantness thresholds about 8 to 10 db below pain thresholds. The 2500-cps signal, irrespective of whether it is presented as a steady stimulus, a series of pulses, or a series of beats, is reacted to as "unpleasant" or as "painful" at a slightly, but consistently lower intensity level than the corresponding 1000-cps tone. At each frequency used, intermittent tones are judged as "unpleasant" or "painful" at lower intensity levels than steady tones. The differences are slight but consistent. Repetition rates of three pulses or beats per second were fairly consistently found to have a lower unpleasantness and pain threshold than either 6 or 15 per sec. In general, pain thresholds seemed to be related primarily to power per pulse, rather than total energy in a series of pulses.

Various studies have shown that low frequency intermittent auditory stimulation affects humans in a variety of ways (Plutchik, 1959). For example, it sounds louder than equal intensity tones produced by steady stimuli (Garner, 1948). Such intermittent stimuli depress blood oxygen-saturation levels (Lovett-Doust, Hoenig & Schneider, 1952), and they affect EEG rhythms (Goldman, 1952; Neher, 1961; Plutchik, 1962).

An earlier study (Plutchik, 1957) has shown that auditory pain thresholds are affected by both frequency and intermittency rate of acoustic stimuli used, within the range of 1 to 15 pulses per sec. The experiment reported here is designed to follow up these preliminary findings through the use of a larger number of Ss and a more intense examination of certain selected points on the frequency and pulse rate dimensions. As a further extension of the problem a comparison will also be made of thresholds obtained with comparable steady stimuli, and with "beats."

METHOD

The interrupted tones were produced by modulating the sine-wave frequency produced by an audio oscillator (Hewlett-Packard Type 200 AB) with a square-wave pulse, produced by a wave-form generator (Tektronix, Type 162) and a pulse generator (Tektronix, Type 161). In all cases, the pulse duration used was 40 msec. The modulated stimulus was amplified to a given predetermined intensity level, fed to a 45-db attenuator calibrated in 1-db steps, and then brought to Ss' binaural head-set, consisting of a pair of PDR-8 earphones with doughnut cushions previously calibrated by the Permaflux Company into a 6-cc. coupler. The frequency response of the headphones is essentially flat between 200 and 4000 cps. An additional calibration check was made at the Dictograph Corporation and calibration curves drawn up. The maximum intensity was determined at 130 db $\pm$ 2 db (re: 0.0002 dynes/cm. sq.).

The "beat" stimuli tones that were used were obtained by using two Hewlett-Packard audio oscillators in parallel set so that the difference between the two frequencies produced beats at the desired rate. This condition was utilized in order to check on the effects of the transients which are produced in the earphones whenever a square-wave pulse activates the diaphragm. Calibration of an oscilloscope showed that the difference between the peak and trough of the beats for all conditions was 17 db.

In order to have a permanent record and check on the actual beat frequencies used, a "beat frequency detector" was built to demodulate the beat signal going to S and to feed the detected beat frequency to the power amplifier of the Grass pen recorder.

Eight male college students (paid volunteers) were used; ages 19 to 28, with a median age of 22 yr. Each was tested separately on a Maico audiometer and found to be within $\pm$ 15 db of the normal threshold value for all frequencies between 125 cps and 8000 cps. The eight Ss were then given an ear examination by a medical ear specialist, to insure the lack of organic pathology of any kind. After the completion of the experiment, audiograms were again taken for all Ss, and were found to be essentially unchanged from the pretest records.

In the experimental situation, each S was told that he would hear a series of tones which would increase by steps in loudness and that he was to indicate with the response "Yes" when a tone was "just noticeably unpleasant." After this point was reached, the tones would continue to increase in loudness by a series of steps until one seemed "just noticeably painful," at which time a new frequency or repetition rate would be started in an ascending series. Each series began at a different point and the tones were increased 3 or 4 db per step by use of the calibrated 45-db attenuator.

Each tone lasted 4 sec. and each interval between tones lasted 4 sec. Several practice trials were given to each S before any data were recorded and S was told

to make his judgment at the *end* of the 4-sec. period during which the tone was on.

Two audio frequencies, 1000 cps and 2500 cps, and three repetition rates, 3, 6, and 15 pulses per sec. were chosen on the basis of the pilot study in order to cover a wide range of rates. The different conditions were presented in counterbalanced orders.

RESULTS

Individual pain thresholds were found to vary from approximately 102 db to over 130 db and "unpleasantness" thresholds from 95 db to about 125 db. If the "just noticeably unpleasant" (JNU) and "just noticeably painful" (JNP) thresholds for the two frequencies are compared under the beat, pulse, or steady conditions, and for corresponding repetition rates, the mean attenuation is larger for the 2500-cps tones in 12 out of 14 comparisons. This can be seen in Table 1.

Examination of this table shows that in all cases except one (seven out of eight comparisons) the over-all mean attenuation for 3 beats or pulses per sec. is greater than for either 6 or 15 per sec. The absolute difference in db in most cases is not large, and individual variation is marked, yet the application of *t* tests shows two highly significant differences. Using pulsed tones, at 1000 cps, both the JNU and JNP mean attenuations at 3 pulses per sec. are significantly larger than at 15 pulses per sec. In general, 3 pulses per sec. produces a larger attenuation than 15 pulses per sec. under all conditions. In addition, it can also be seen that intermittent tones are judged as "unpleasant" or "painful" at lower intensity levels than comparable steady tones. This was found in 21 out of 24 comparisons.

If the relative energy at 3, 6, and 15 pulses per sec. is computed, the results can be plotted as in Fig. 1. The curve is almost linear showing that about 14 times as much acoustic energy is used to produce a pain response at 15 pulses per sec. than at 3 pulses per sec. This simply reflects the fact that the intensity of each individual pulse at pain threshold is fairly similar at all pulse rates so that the energy per second is almost directly proportional to the pulse rate per second. The slight deviation from a straight line in Fig. 1 is due to the fact that the pain threshold at 3 pulses per sec. is a little lower than at 6 or 15 pulses per sec. This implies that what is significant in determining pain threshold is not the mean power but rather the power per pulse.

DISCUSSION

The pain thresholds found here, defined by the phrase "just noticeably painful," varied for individuals from 102 db to over 130 db with an average of about 123 db. This is consistent with previous reports if one considers the different criteria of "overloading" that have been used (Davis, Parrack, & Eldredge, 1949; Licklider, 1951; Miles, 1953).

TABLE 1

"JUST NOTICEABLY UNPLEASANT" (JNU) AND "JUST NOTICEABLY PAINFUL" (JNP) THRESHOLDS AS MEAN ATTENUATIONS FROM 130 db BASED ON 40 JUDGMENTS EACH

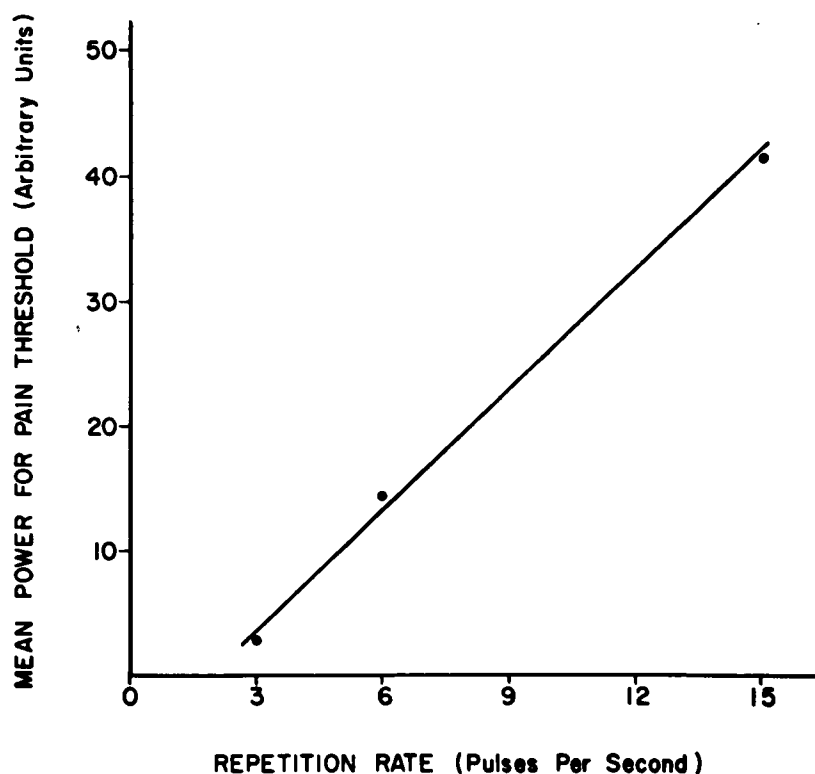| Inter-mittency Rates	Pulses						Beats						Steady	
	1000 cps			2500 cps			1000 cps			2500 cps			1000 cps	2500 cps
	3	6	15	3	6	15	3	6	15	3	6	15		
Mean JNU	18.6	15.5	13.7	15.9	15.7	15.3	15.5	15.2	13.2	18.2	17.2	15.6	12.7	15.1
SD	7.0	8.0	7.5	7.7	8.5	8.8	9.4	9.3	8.0	9.1	8.3	7.5	8.5	9.0
Mean JNP	10.6	6.8	6.2	8.3	7.8	7.2	6.2	6.3	5.4	9.6	8.9	6.9	5.8	7.2
SD	8.7	7.7	6.5	8.0	8.2	7.9	8.4	8.2	6.5	9.3	8.7	7.8	7.0	8.4

FIG. 1. The mean power required for pain threshold, measured in arbitrary units, as a function of repetition rate

There is an interesting relation between the two thresholds—unpleasantness and pain—found in this study. The mean difference between them was found to be approximately 8 db. Stevens (1955) has suggested on the basis of the many studies of loudness scaling that an attenuation from a standard of approximately 10 db represents a tone half as loud as the standard. Garner (1952) has pointed out that this is probably too high an estimate. Therefore, it seems that the "just noticeably unpleasant" threshold is approximately half as loud on a ratio scale as the "just noticeably painful" threshold.

The findings that intermittent tones are judged as "unpleasant" or "painful" at lower intensity levels than steady tones is also consistent with previous reports. Both Garner (1948) and Pollack (1952) found that a series of pulses may be louder than a steady tone of the same intensity level and that this effect is relatively greater at frequencies between 1000 and 4000 cps, and rates between 2 and 10 pulses per sec.

A related phenomenon in vision is the Bartley Effect, i.e., a flickering light with a pulse rate in the neighborhood of 10 per sec. (the alpha rhythm of the human) seems brighter than a steady light whose brightness is the same as that of the individual pulses (Bartley, 1939, 1952).

Another publication of relevance is the report of Zeitlin (1957) on the relative loudness of pure and complex tones. In this study, it was found that a square-wave tone produced a series of harmonics which were greater for lower frequencies (under 700 cps) because of the limited frequency response of the PDR-8 earphones. Even when the square-wave complex tone was matched for equal loudness with a pure sine-wave tone, there was an intensity difference of 3.2 db at 1000 and 2000 cps in favor of the pure tone. This is also consistent with the present finding that, when the steady and intermittent tones are of equal loudness, i.e., at the pain or unpleasantness threshold, the intermittent stimuli are of lower intensity. The magnitude of the intensity difference found is also consistent with Zeitlin's finding. All these observations suggest that the increased loudness of interrupted acoustic stimuli relative to steady ones is probably due to the various harmonics and transients that are produced by the interruptions.

The other major observation of this experiment—that 3 pulses or beats per sec. tends to be more unpleasant or painful than other rates—raises some interesting questions. For example, Garner (1947) has noted that the total energy in a stimulus is directly proportional to the repetition rate; thus 6 and 15 pulses per second should have more acoustic energy than 3 pulses per second. In fact, according to Garner, each doubling of the repetition rate changes the total energy by 3 db. It should also be noted that in the pilot study reported earlier (Plutchik, 1957), a pulse rate of 1 per sec. was used at all frequencies and was found to produce higher pain thresholds than at 3 per sec. This suggests that there may be something particularly significant about an auditory pulse rate of 3 per sec., relative to either faster or slower rates.

In this connection, several previous studies have found that stimulus inputs at about 3 cps produce appreciably different responses than do either higher or lower frequencies. For example, in a review of the literature on audiogenic seizures in animals Bevan (1955) cites one experiment which showed that an intermittent pure tone at 9,500 cps, with a 3-cps interruption rate was most effective in producing convulsions. This may be related to the fact that certain EEG potentials found in epilepsy are of this order of frequency.

Two studies of evoked potentials found something similar. In one, records were obtained from single neurons in the unanesthetized cat's visual cortex while a black-white border was moved at various frequencies in front of the eye. It was found that the maximum neuron response occurred at an oscillation frequency of about 2 to 4 cps (Burns, Heron, & Pritchard, 1962). In a related

study in cats of the effects of reticular stimulation on the response to acoustic clicks, it was found that suppression of response was frequently found for click inputs below 3 cps. In contrast, click inputs over 3 cps frequently were associated with facilitation of evoked response, thus suggesting the possible introduction of a different mechanism or variable at about this frequency (Steriade & Demetrescu, 1962).

In two other experiments using human adults, unexpected effects occurred at stimulus inputs of about 3 cps. Stark, Iida, and Willis (1961) had Ss try to follow the cyclic movement of a pointer by rotation of a handle. They report that the accuracy of following shows a resonant peak at 3 cps. Similarly, Parks and Snyder (1961), in a study of human reactions to low frequency vibration, found that Ss reported the most annoying and alarming frequencies of vibration to be at 2 to 3 cps.

All these reports suggest the hypothesis that stimulus inputs at low frequencies in the range of approximately 2 to 4 cps, either interact with already existing body rhythms at those frequencies or create certain resonance effects. In any event, the appearance of this same frequency range in several different experiments implies that some common element may possibly be involved.

REFERENCES

BARTLEY, S. H. Some factors in brightness discrimination. *Psychol. Bull.*, 1939, 46, 337-357.

BARTLEY, S. H. Visual responses to intermittent stimulation. *Optical J. Rev.*, 1952, 89, 31-33.

BEVAN, W. Sound-precipitated convulsions: 1947 to 1954. *Psychol. Bull.*, 1955, 52, 473-504.

BURNS, B. D., HERON, W., & PRITCHARD, R. Physiological excitation of visual cortex in cats' unanesthetized isolated forebrain. *J. Neurophysiol.*, 1962, 25, 165-181.

DAVIS, H., PARRACK, H. O., & ELDREDGE, D. H. Hazards of intense sound and ultrasound. *Annals Otol. Rhinol. and Larnygol.*, 1949, 58, 732-738.

GARNER, W. R. Auditory thresholds of short tones as a function of repetition rates. *J. Acoust. Soc. Amer.*, 1947, 19, 600-608.

GARNER, W. R. The loudness of repeated short tones. *J. Acoust. Soc. Amer.*, 1948, 20, 513-527.

GARNER, W. R. Some statistical aspects of half-loudness judgments. *J. Acoust. Soc. Amer.*, 1952, 24, 153-157.

GOLDMAN, D. The effect of rhythmic auditory stimulation on human electroencephalogram. *EEG. clin. Neurophysiol.*, 1952, 4, 370. (Abstract)

LICKLIDER, J. C. R. Basic correlates of the auditory stimulus. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951. Ch. 25.

LOVETT-DOUST, J. W., HOENIG, J., & SCHNEIDER, R. A. Effect of critical flicker frequencies on oximetrically determined arterial blood oxygen-saturation levels. *Nature*, 1952, 169, 843-845.

MILES, W. R. Immediate psychological effects. In Benox Report, *An exploratory study of the biological effect of noise*. Chicago: Univer. of Chicago, Dec., 1953. (ONR Project NR 144079)

NEHER, A. Auditory driving observed with scalp electrodes in normal subjects. *EEG. clin. Neurophysiol.*, 1961, 13, 449-451.

PARKS, D. L., & SNYDER, F. W. Human reaction to low frequency vibration. *ONR Report D3-3512-1*, 24 July, 1961.

PLUTCHIK, R. A critical analysis of the literature dealing with the effect of intermittent sound stimuli on performance, feeling, and physiology, with preliminary work toward an experimental analysis of the problem. ONR Contract NONR-2252 (01). *Tech. Rep.* No. 1, October, 1957.

PLUTCHIK, R. The effect of high intensity intermittent sound on performance, feeling and physiology. *Psychol. Bull.*, 1959, 56, 133-151.

PLUTCHIK, R. Studies of the effect of high intensity intermittent sound on human behavior and physiology. *ONR Third Symposium on Physiological Psychology*, in press.

POLLACK, I. Auditory flutter. *Amer. J. Psychol.*, 1952, 65, 544-554.

STARK, L., IIDA, M., & WILLIS, P. A. Dynamic characteristics of the motor coordination system in man. *Biophysical J.*, 1961, 1, 279-300.

STERIADE, M., & DEMETRESCU, M. Reticular facilitation of responses to acoustic stimuli. *Electroenceph. Neurophysiol.*, 1962, 14, 21-36.

STEVENS, S. S. The measurement of loudness. *J. Acoust. Soc. Amer.*, 1955, 27, 815-829.

ZEITLIN, L. R. *The relative loudness of pure and complex tones.* Fort Knox, Ky.: U.S. Army Medical Res. Lab., 25 Sept., 1957. (Rep. No. 286)